



Transport  
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TP 5321E

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## **M. V. Arctic Ice Transiting Performance (Ramming Mode)**

### *Summary Report*

Prepared for  
Transportation  
Development Centre

MAY 1984

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**Canada**

ARCTEC CANADA LIMITED

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MV ARCTIC  
ICE TRANSITING PERFORMANCE  
IN THE RAMMING MODE

SUMMARY REPORT  
TP 5321E

A.M. NAWWAR  
L. GOOSSENS

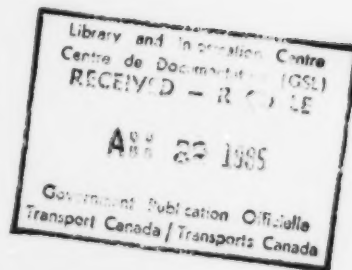
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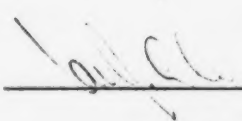
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## AVIS:

Ce rapport est également disponible en français.

# REPORT DOCUMENTATION FORM

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| 17. Abstract<br><br>This report presents the methodology and results of a study of the MV ARCTIC ice transiting performance in the ramming mode. The report provides an account of ramming mode formulations which include resistance models, performance formulation and ship motions and accelerations. It describes the methods and instruments used in data scanning, categorization and quality assessment. A core database comprising dedicated trials of the Admiralty Inlet trials, 1981 was used as a basis for the analysis because of its higher quality. Data reduction and primary analysis were conducted on an HP9816 computer-based system. The data reduction algorithms are described including a comprehensive speed correction methodology. Results are presented in a standardized graphical format. The MV ARCTIC performance is analyzed and simulated. The analysis includes the effects of acceleration distance, speed of impact, thrust cut off, ice thickness, bubbler operation, trim condition and power level on performance. The latter is measured by average speed of advance and fuel consumption. The analysis also includes cycle time diagnosis. Performance simulation is presented for one model ram to demonstrate the applicability of simulation to analysis and optimization of the MV ARCTIC performance. The CASPPR power requirements, ship design features and instrumentation system has been evaluated. The report is concluded by recommendations for designers and operators of ARCTIC class cargo vessels, and for supplementary evaluation. |                                                            |                                                                 |                  |
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| 17. Résumé<br>Ce rapport présente les méthodes et résultats de l'étude concernant le comportement dynamique et l'efficacité de l'Arctic lors de la charge des glaces. Il donne les équations élaborées concernant: la résistance à l'avancement, les performances, les mouvements et les accélérations. Il décrit les méthodes et instruments utilisés pour la scrutation des capteurs ainsi que le classement et l'appréciation qualitative des données obtenues. La base de données utilisée était formée essentiellement des résultats obtenus en 1981 lors des essais spécialisés dans l'Inlet de l'Amirauté, et retenus à cause de leur haute qualité. Le rapport décrit les algorithmes qui ont servi à la réduction des données ainsi que la méthode utilisée pour la correction automatique des vitesses. Le comportement dynamique et l'efficacité en marche alternée de l'Arctic sont analysés et simulés, les paramètres pris en compte pour évaluer l'efficacité du navire étant: la distance d'accélération, la vitesse à l'impact, le moment de coupure de la poussée, l'épaisseur des glaces, le fonctionnement ou non du système à bulles d'air, l'assiette du navire et la puissance effective développée. L'efficacité du navire est mesurée par la vitesse moyenne d'avancement et la consommation correspondante. Les dispositions de la loi canadienne sur la prévention de la pollution des eaux arctiques ont été évaluées, notamment en ce qui concerne la puissance, la conception de la coque et l'instrumentation. Enfin, le rapport adresse des recommandations aux constructeurs et aux armateurs de navires marchands de cote arctique et suggère une évaluation plus approfondie. |                                                                  |                                                                     |                                                             |
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# ***SUMMARY REPORT***

## 1. INTRODUCTION

The MV ARCTIC is the first Arctic Class 2 bulk carrier to be designed and built in accordance with the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR). Since its delivery in 1978, the MV ARCTIC has been primarily operating to and from Nanisivik Harbour in the Canadian Arctic. The ship was fitted with a computerized data acquisition system and data has been collected during three Arctic operating seasons from 1979 through to 1981. The data have been documented in various project reports each season and was summarized in a Master Data Package in 1982 which represents a comprehensive record of four dedicated trials and several Arctic voyages.

Transport Canada has commissioned five independent studies to analyze and evaluate various aspects of the performance and capabilities of the ship. This study is only concerned with the ice transiting performance in the ramming mode of operation.

The overall objective of this study is to establish the ramming mode and ridge penetration capabilities of the MV ARCTIC and its design features including the bubbler system and to provide and demonstrate some means of performance formulation which permits the utilization of the findings of this study into the operation of the MV ARCTIC and the design of other Arctic Class cargo ships.

## 2. STUDY APPROACH AND RESULTS

### 2.1 Approach

The study approach is outlined in Figure 1. It has been structured at various levels to address the various requirements and objectives of the study.

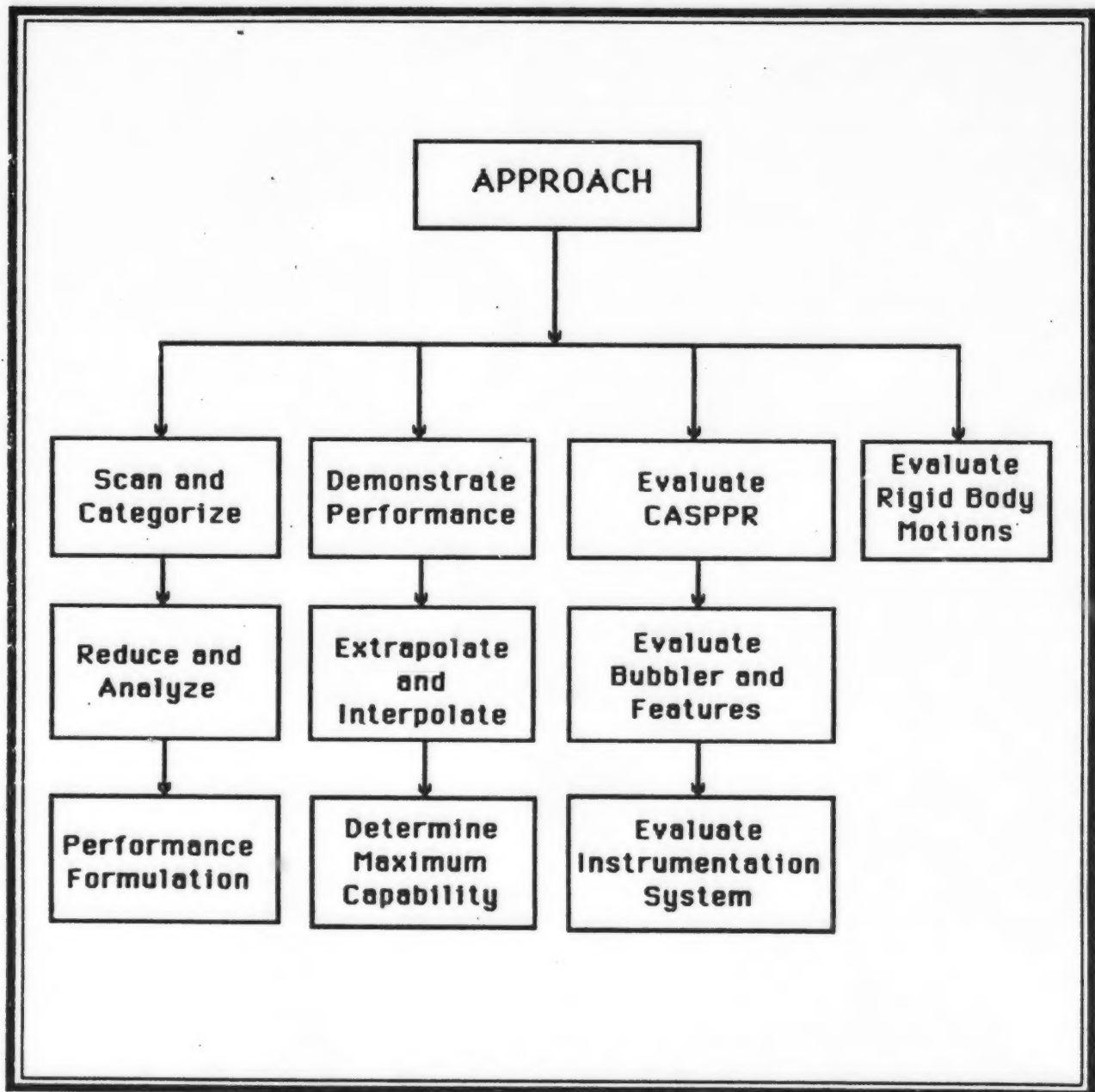
Methods of data reduction, validation, correction and analysis have been developed and used in the assessment of performance of the MV ARCTIC in the ramming mode and evaluation of its various design features, and instrumentation system as well as the CASPPR power provisions.

Following the data scanning it was possible to distinguish two major categories of data:

- a) dedicated trials of the Admiralty Inlet (1981), which contained most of the better documented ramming incidents with respect to operating and ice conditions.
- b) Arctic voyages which contained a number of ramming incidents but with much less known about the ice conditions.

Each category required a different analysis approach to data interpretation. Data from the first category lends itself to the conduct of rigorous analysis and interpretation and was used to establish a "core data base" which formed the basis for the present study.

FIGURE 1  
OVERALL STUDY APPROACH



The core data base was categorized into two primary categories being level ice and pressure ridges. For each primary category four secondary categories were established which accounted for combinations of bubbler status and trim condition.

The quality of data was assessed on the basis of the quality of records, quality and quantity of expected output, and the availability of ice characteristics.

In the present study the ramming cycle was analyzed in terms of its fundamental functions, including backing and acceleration in broken channel, penetration of solid unbroken ice, and finally extraction of the ship and proceeding with the next ramming cycle. Models were developed for the MV ARCTIC resistance in broken channels (ahead and astern), level ice, and transition between continuous and ramming modes. A corresponding action cycle was developed on the basis of pitch setting: astern, reversal to ahead, ahead, and reversal to astern.

It should be noted that the effective (total) thrust was determined using a more direct engineering approach based on model scale propulsion and overload experiments conducted at the NRC laboratories. Also algorithms were developed to perform self-correction of the data to ensure the compatibility between speeds, distances travelled and measurements of speed and time during the trial.

## 2.2 Results of Standard Analysis

Standard analysis refers to the application of the data reduction program to a standard case of ramming. A standard case is necessarily complete with backing, acceleration and penetration. Reference may be made to Figure 2(a) which illustrates an idealized ramming cycle which consists of an action cycle and a response cycle and related components. These components formed the basis of the standard analysis procedures. The standard analysis provides complete speed correction, thrust and resistance analysis, cycle time analysis, and fuel calculations. It produces a standardized set of results consisting of one summary data sheet and five sets of graphical output as illustrated for Ram No. C-6 in Figure 2(b).

## 3. PERFORMANCE ANALYSIS

### 3.1 General

The analysis of performance of the MV ARCTIC was divided into three sections dealing with three different aspects of performance assessment:

- a) Analysis of performance under trial conditions or the As-Is performance which focussed on the effects of several variables on the ship performance in level ice and pressure ridge penetration without attempting to optimize the performance.
- b) Performance Simulation in which the techniques which can be used for ramming simulation have been demonstrated. Such techniques would permit future detailed analysis and optimization of the ramming operations of ships similar to the MV ARCTIC.

FIGURE 2(a)

IDEALIZED RAMMING CYCLE AND COMPONENTS

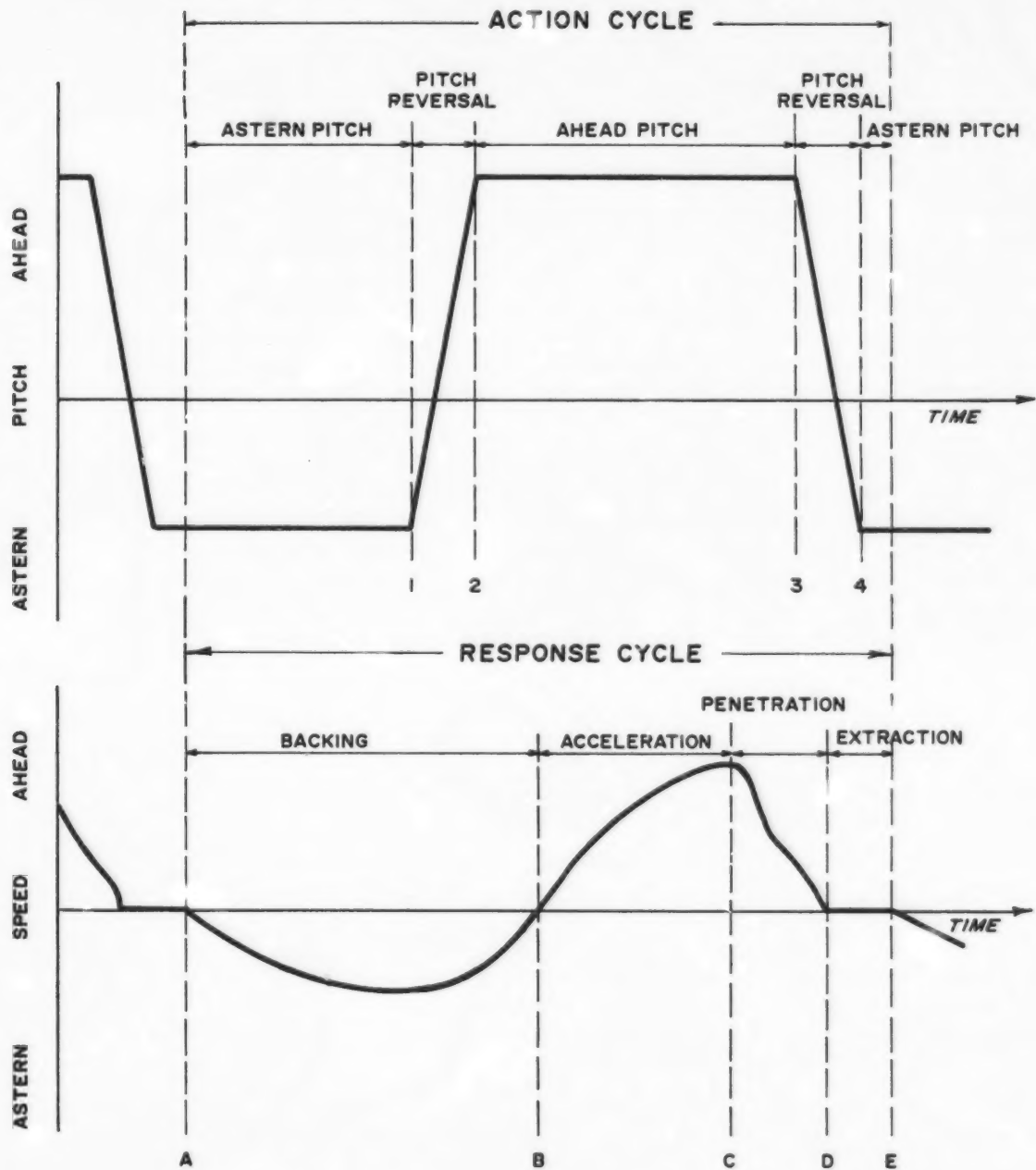


FIGURE 2(b) RESULTS OF STANDARD ANALYSIS

RESULTS OF NAVING CYCLE ANALYSIS

RAM #1 C6 TAPE: 81-T2-5.1 88 JUL 1981 14:12:39 FIG. #1

NAVING CYCLE CHARACTERISTICS:

Speed of Advance (knots) .289  
Speed of Impact (knots) 6 (4.25)

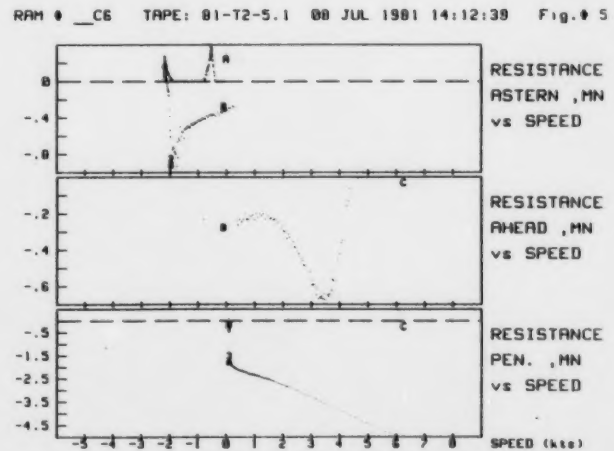
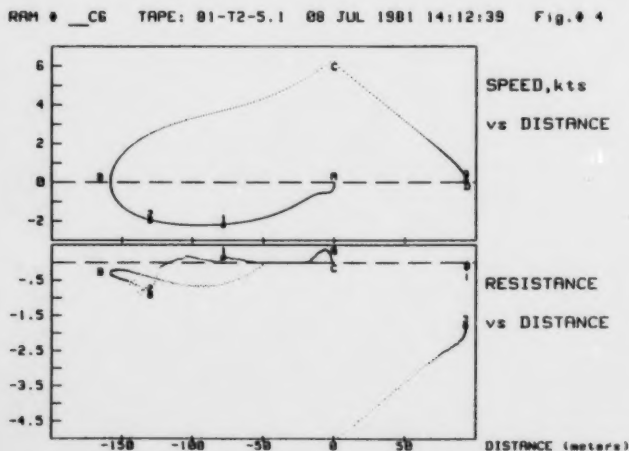
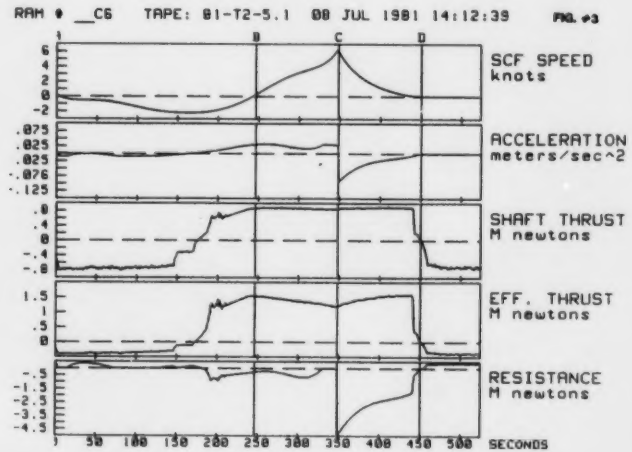
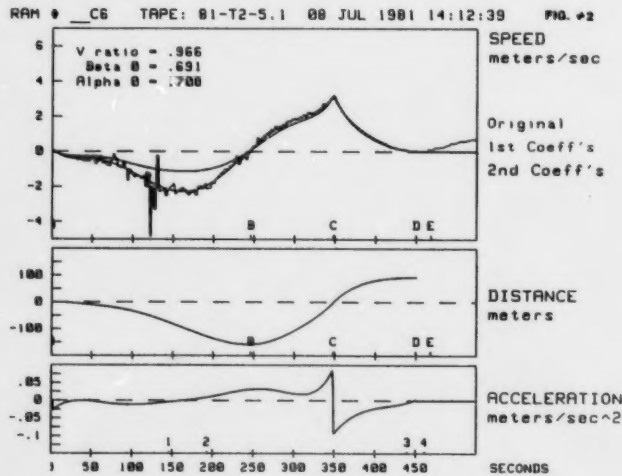
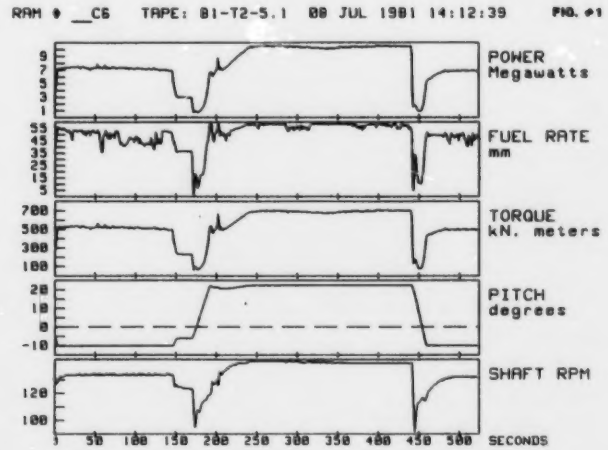
|              | Duration (sec) | % Cycle Time | Distance (m) |
|--------------|----------------|--------------|--------------|
| Backing      | 246            | 32.6         | -138         |
| Acceleration | 102            | 13.3         | 138          |
| Penetration  | 102            | 13.3         | 97 (93.25)   |
| Extraction   | 18             | 2.35         |              |
| Total Cycle  | 468            |              |              |

|                                      |     |
|--------------------------------------|-----|
| Duration of Return Mode (sec)        | 146 |
| Duration of Reversal to Ahead (sec)  | 47  |
| Duration of Ahead Mode (sec)         | 247 |
| Duration of Reversal to Astern (sec) | 21  |
| Start of Reversal after Impact (sec) | 62  |

|                           |        |                   |
|---------------------------|--------|-------------------|
| Total Fuel Used (lb/hr)   | 6.53   | Est. hp 108.1     |
| Average Fuel Rate (lb/hr) | 55.12  | Est. hp/hr 821.76 |
| Backing Power (kW)        | 7165.9 |                   |
| Est Fuel Rate (kg/hr)     | 1326.7 |                   |
| Acceleration Power (kW)   | 9480.6 |                   |
| Est Fuel Rate (kg/hr)     | 2022.6 |                   |



- c) Ultimate Performance assessment which dealt with the analysis and synthesis of ramming cycle components to determine the maximum capabilities of the MV ARCTIC in ramming.

The results of each of these aspects will be summarized in the following sub-section:

### 3.2 Performance Under Trial Conditions

The acceleration distance and power level during acceleration affect the speed of impact at the end of the broken channel. The latter, in turn, influences the penetration capability and the average speed of advance. This is illustrated in Figure 3 (a) and (b). It is shown in Figure 3(a) that the effect of increasing the acceleration distance tapers off as the distance increases, which means that no significant benefit can be achieved by backing a greater distance because of the speed limitation in the broken channel. This speed limit also appears to be dependent on the ice thickness.

The effect of speed of impact on speed of advance is demonstrated in Figure 3 (b). It is shown that there is an optimum impact speed for which maximum progress is achieved. This optimum speed depends on the ice thickness and operating conditions of the ship and is lower than the maximum speed in broken channel. Examination of the data has shown that much improved performance was observed when the ship was operating in the bubbler ON, bow UP condition. Further examination of data categories with either bubbler on or bow up indicated that there was no evidence of different performance. Hence it was concluded that the effects of bubbler and trim were comparable under the ramming conditions investigated.

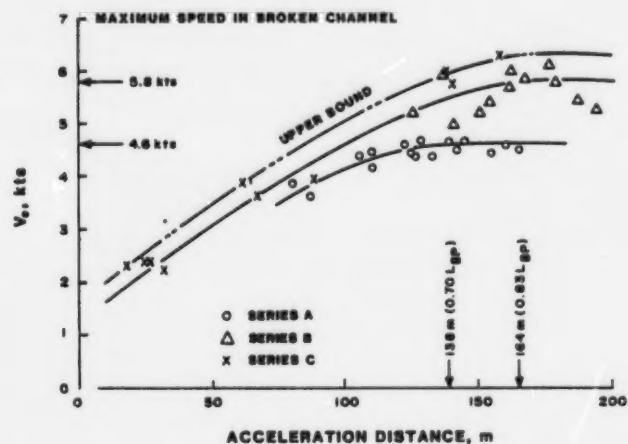
The effect of thrust cut-off on impact was also investigated during the trials of the MV ARCTIC. While it is obvious that the thrust application during the penetration stage would provide more energy and hence allow longer penetration, the question was how much did the thrust contribute to the ship performance and whether it was advantageous to cut-off thrust during penetration to facilitate extraction. Figure 4 shows the results of two ramming incidents conducted under comparable conditions. It can be seen that maintaining thrust (or power) during the penetration stage is extremely beneficial. However, the benefits of increased penetration distance reduce when thicker ice is encountered and the penetration distance is shorter.

Examination of the effect of ice thickness on fuel consumption indicated a direct correlation between the fuel used per unit distance travelled (e.g. kilogram or ton per nautical mile or kilometer) and ice thickness. The ice thickness was observed to be a dominant parameter in characterization of an ice field. Figure 5 gives the performance curves of the MV ARCTIC under trial conditions for different average fuel flow rates. The average fuel rate is given in millimetres or percentage setting. It is suitable for prediction of the average speed of advance ( $v_a$ ) in ice using current operational strategies.

The effect of operating power level ahead could not be directly evaluated because throughout the trials the target was full power ahead.

FIGURE 3

(a) EFFECT OF ACCELERATION DISTANCE ON SPEED OF IMPACT



(b) EFFECT OF SPEED OF IMPACT ON SPEED OF ADVANCE

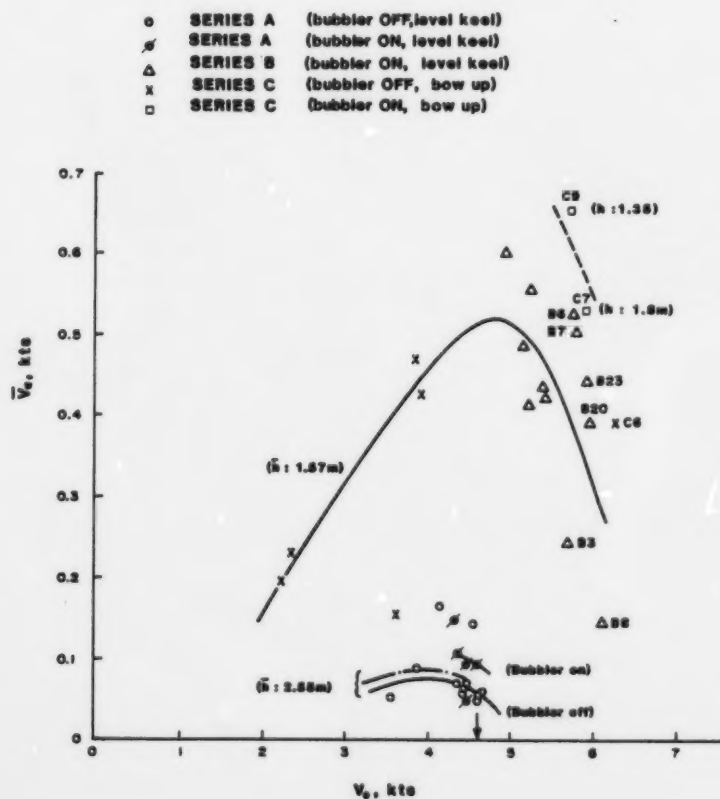
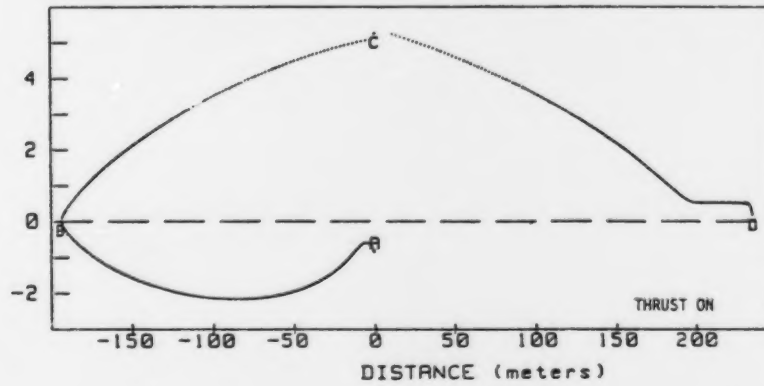


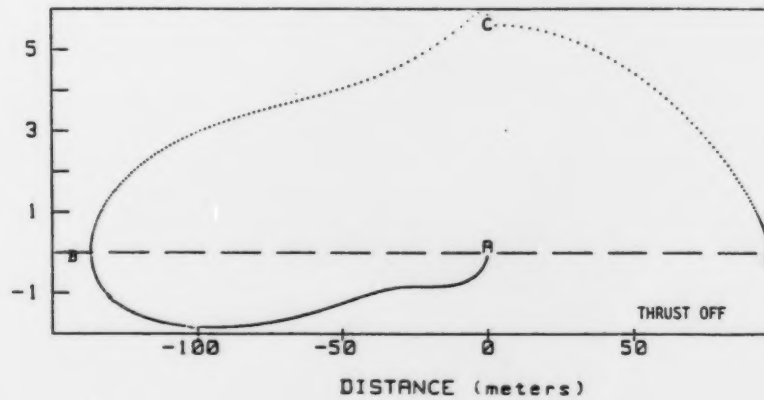
FIGURE 4

EFFECT OF THRUST CUT-OFF ON PENETRATION

RAM # \_B22 SPEED, kts vs DISTANCE



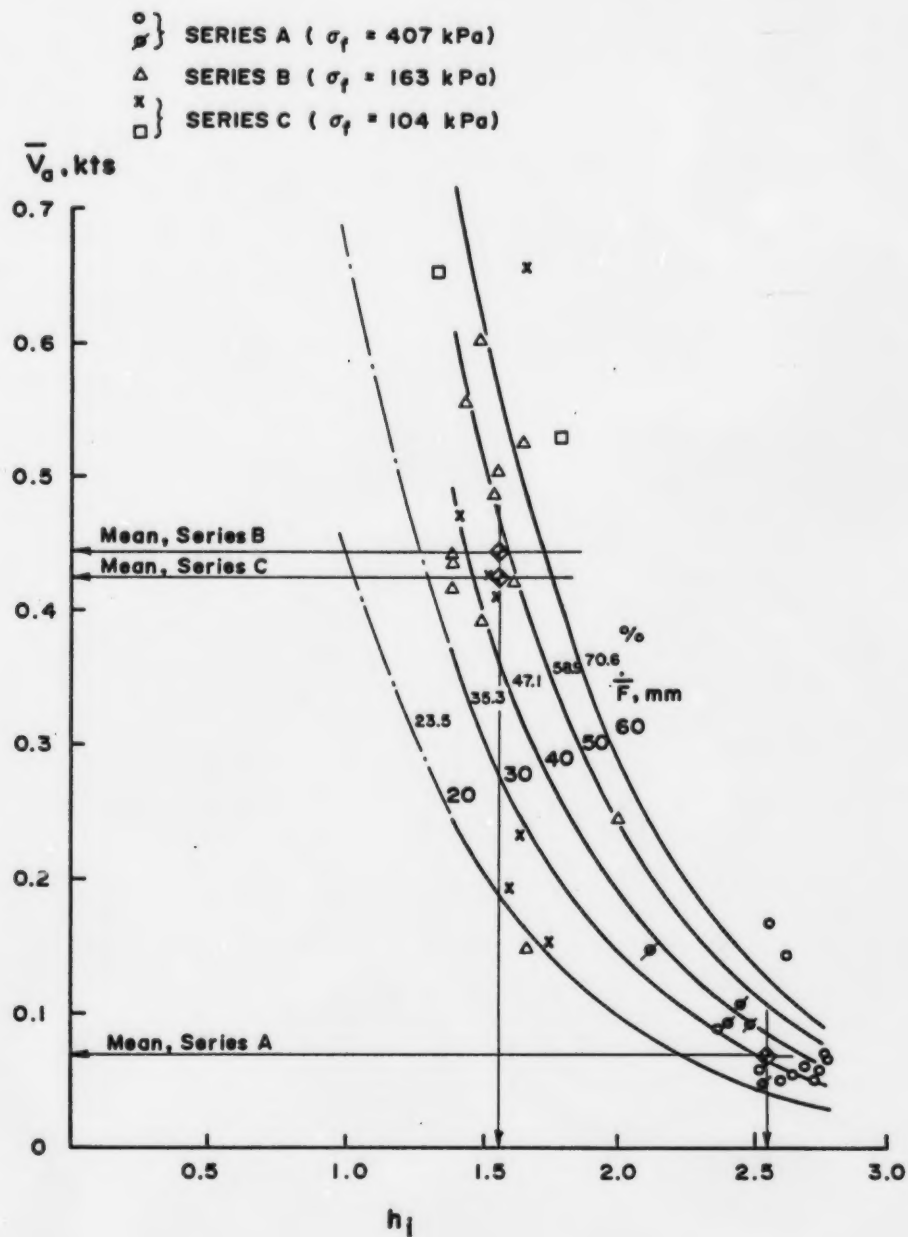
RAM # \_B23 SPEED, kts vs DISTANCE



LEGEND: A-B = Backing phase  
B-C = Acceleration phase  
C-D = Penetration phase

FIGURE 5

MV ARCTIC PERFORMANCE MODEL IN RAMMING MODE



This was adhered to with some inefficiencies. It was estimated, however, that a 10% power reduction would lower the speed of advance by 10% and reduce the fuel mileage (increase fuel consumption) by 3 to 8%. The astern power effect was evaluated and a summary of relevant results will be discussed in the following subsections.

A study of the cycle time components has demonstrated that there are several pay-off areas for improving ramming strategies. The first is by reducing the astern mode duration and the second by reducing the reversal time from astern to ahead particularly in very thick ice (or pressure ridges). Figure 6 shows typical examples of inefficient pitch reversal which impose an unnecessary time penalty on the ship progress. These should be avoided in ramming operation.

### 3.3 Performance Simulation

Simulation of the MV ARCTIC performance was performed by using a model developed in closed form on the basis of MV formulations of:

- total thrust as a function of ship speed at any given power level in the range of interest, and
- total ice resistance to ship motion ahead and astern in broken channel and ahead in unbroken solid ice.

Using this simulation, Ram No. C-6 was regenerated using the action cycle determined during the trials. The predicted response cycle is shown in Figure 7 in terms of speed versus distance plot. This compares well with the measured response as shown in Figure 2. The overall prediction of cycle time was good and the penetration distance was 10% below field observation. The effect of thrust cut-off was also predicted to reduce the speed of advance by an estimated 32 percent, as indicated in the figure.

### 3.4 Assessment of Ultimate Capabilities

The ultimate capabilities of the MV ARCTIC were determined by optimization of the components of the ramming cycle. For each component individual ramming incidents were evaluated with respect to ice thickness, ahead and astern power levels, bubbler and trim status, thrust cut-off, and execution of the procedures. For various conditions of ice thickness and power levels, each component was plotted in three forms:

- Distance vs. impact speed
- time vs. impact speed
- time vs. distance

Using these plots, trends of the best achievable performance were determined subject to physical constraints and limitations of the ship operation, e.g. maximum acceleration or speed limit in broken channel. These trends were based on well executed rams in terms of the various cycle components.

**FIGURE 6**

**TYPICAL EXAMPLES of EXTENDED REVERSAL DURATION**

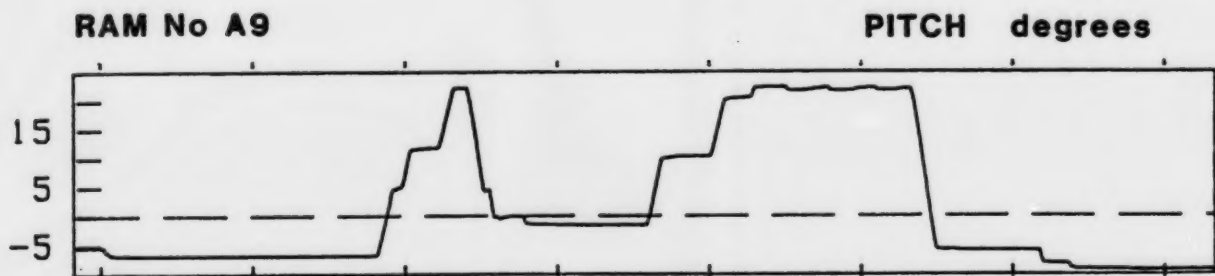
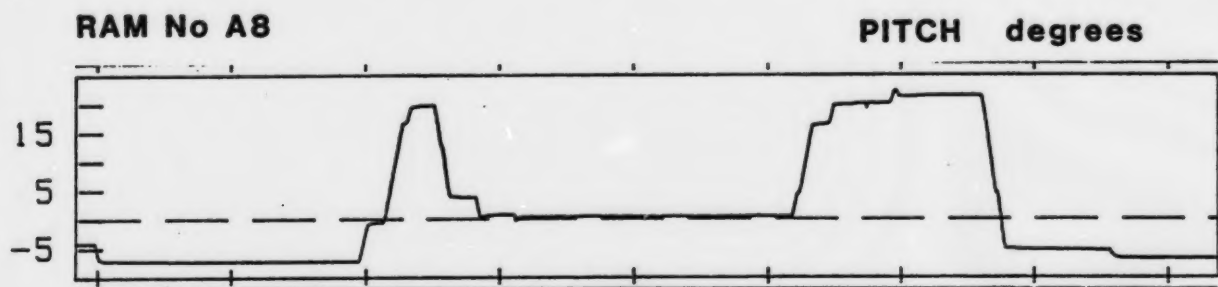
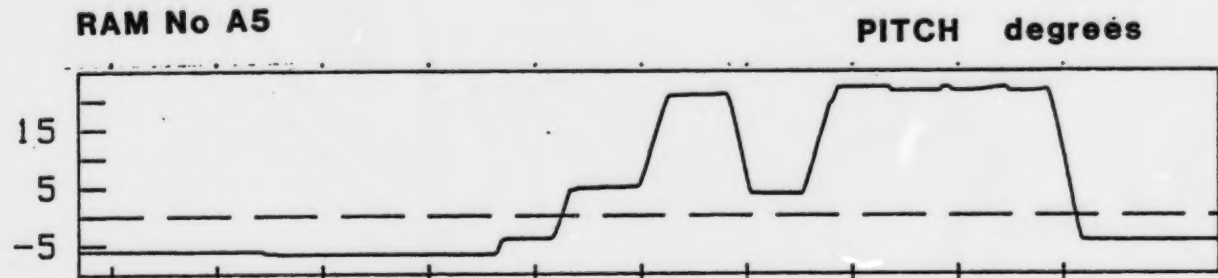
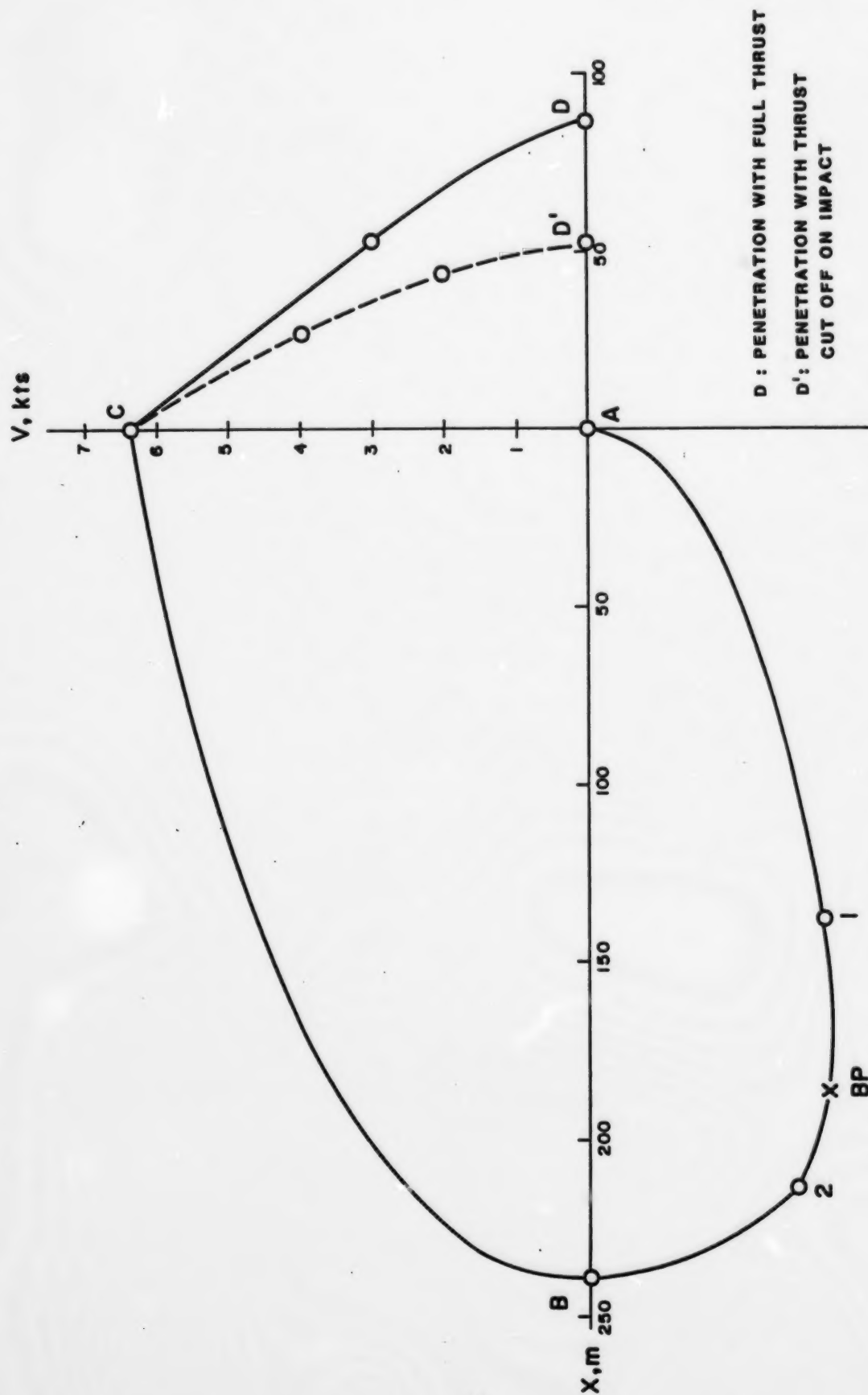


FIGURE 7 REGENERATED SPEED-PENETRATION PLOT FOR RAM No C-6



The MV ARCTIC best achievable performance was then evaluated under the following operational conditions:

- Ice thickness 1.6 m and 2.5 m
- Power level ahead: Full, 10.5 MW  
astern: 5 MW and 7.5 MW
- Efficient reversal from astern to ahead (35 sec)
- Efficient reversal from ahead to astern (20 sec)
- Bubbler on w/level keel and bubbler off w/bow up

Figure 8 is a summary of the acceleration, penetration and backing characteristics of the MV ARCTIC. For a given impact speed one may obtain the necessary backing/acceleration distance, acceleration time, and penetration distance and time as well as the breakdown of the backing distance and time i.e., astern and stopping components.

Using these graphs representing the maximum capabilities of the MV ARCTIC, Figure 9 (a) and (b) were developed. Figure 9 (a) is the speed of advance and fuel mileage vs. impact speed for two power combinations and two ice thicknesses typical of the trials conditions. It is shown that the optima for speed of advance and fuel mileage coincide at about 6.3 and 4.0 knots in 1.6 and 2.5 m thick ice irrespective of the astern power level. For other ice thicknesses and combinations of ahead and astern powers the optimum performance measures may be determined from Figure 9 (b). In this figure it is shown that higher astern power levels are favourable to speed of advance, while lower astern power yields more fuel saving. Henceforth, a compromise between speed and fuel mileage may be made depending on operating requirements. However, in less thick ice the speed of advance can be increased by increasing astern power with a relatively smaller penalty on fuel mileage than in very thick ice. The opposite argument may be used in very thick ice to save fuel with small loss in speed of progress.

By extrapolation of the trends observed in ramming to thinner ice, the speed-thickness characteristics were obtained in the vicinity of the transition zone, as shown in Figure 10 (a). It shows that the transition point occurs in the vicinity of 1.08 m thickness. Between 1.08 and 1.28 m ice thickness, the MV ARCTIC may be able to proceed at very low speed in a continuous but interrupted operation mode. However, it is clearly shown that in this range it is much more advantageous to resort to the ramming mode of operation even if the ship can proceed continuously. Conversely, for ice thinner than the transition thickness (1.08 m) the continuous mode is more advantageous. The best fuel mileage will correspond to the speed of advance.

Figure 10 (b) illustrates the ridge breaching capability of the MV ARCTIC.

### 3.5 Ramming Strategy

The capabilities of the MV ARCTIC can be achieved only under strict operational procedures, which are summarized in the following:

- prompt and decisive operation,
- proper selection of intended procedure of ship operation, based

FIGURE 8

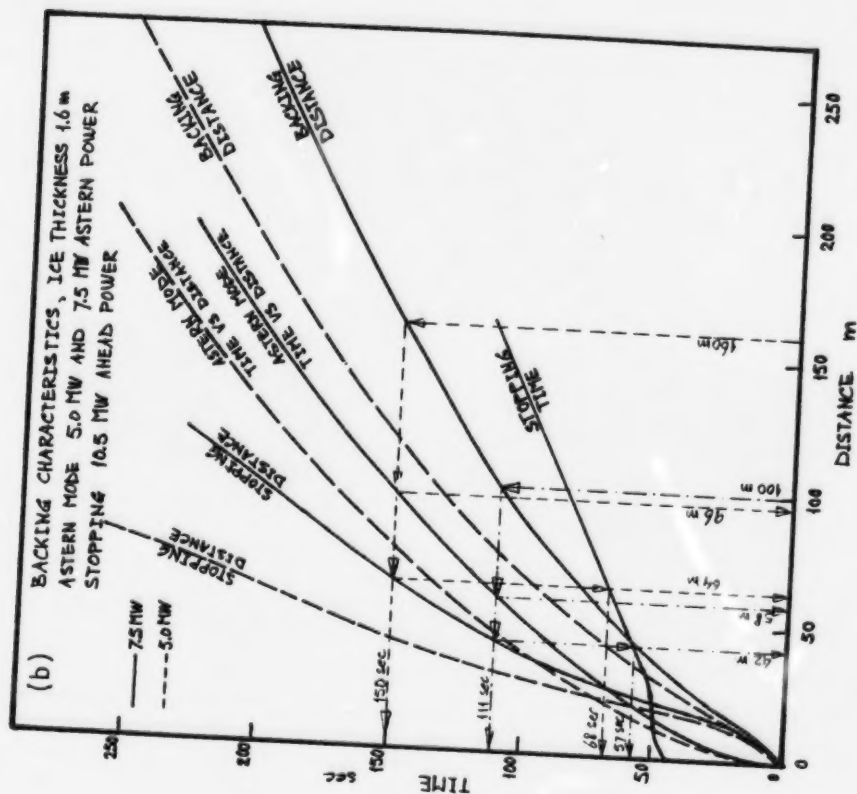
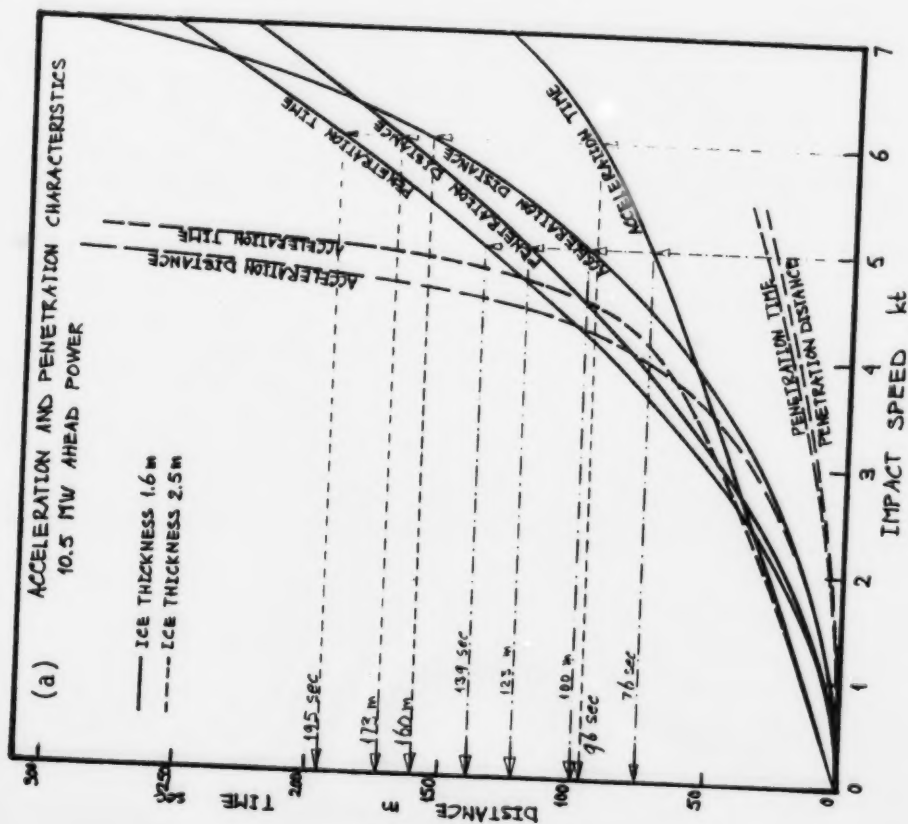
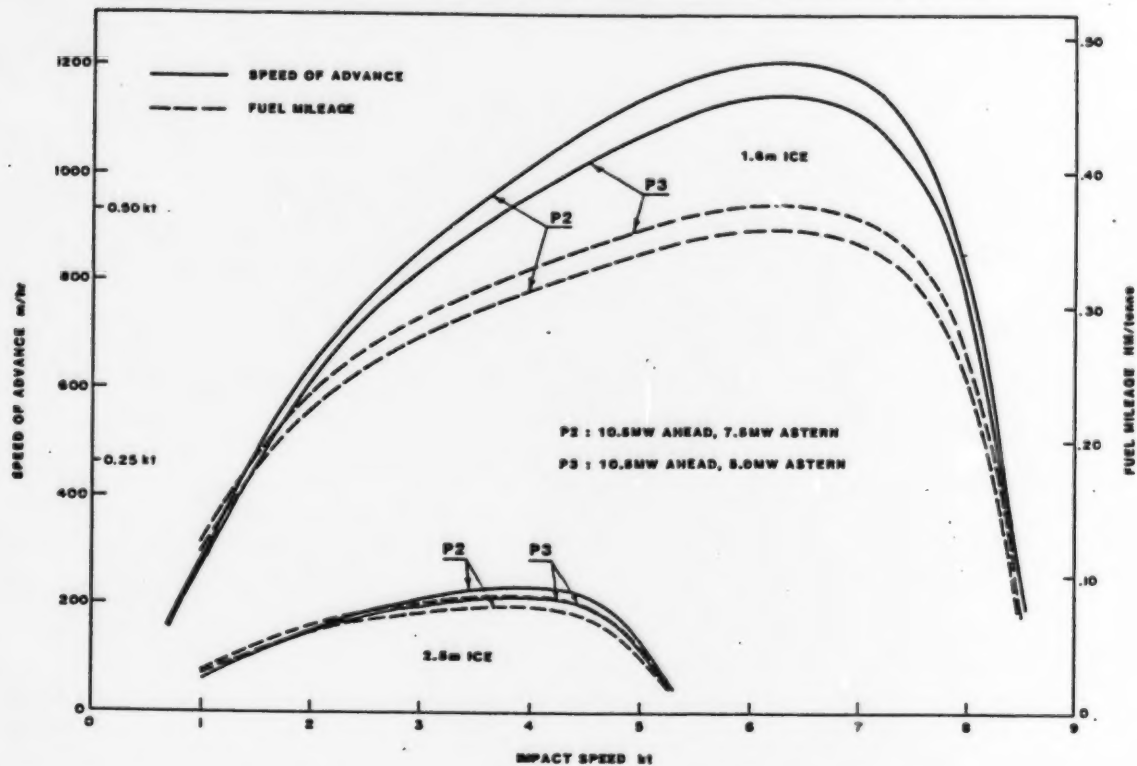


FIGURE 9

(a) SPEED OF ADVANCE AND FUEL MILEAGE VERSUS IMPACT SPEED



(b) OPTIMUM SPEED OF ADVANCE AND FUEL MILEAGE VERSUS ICE THICKNESS

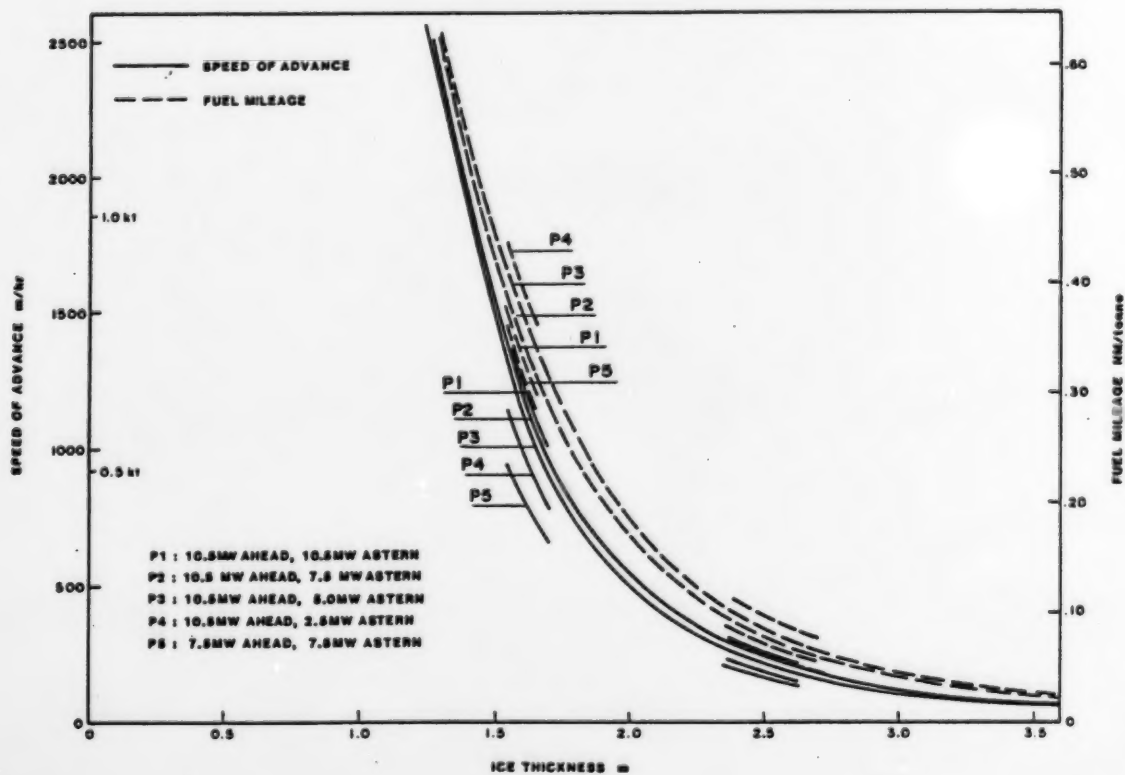
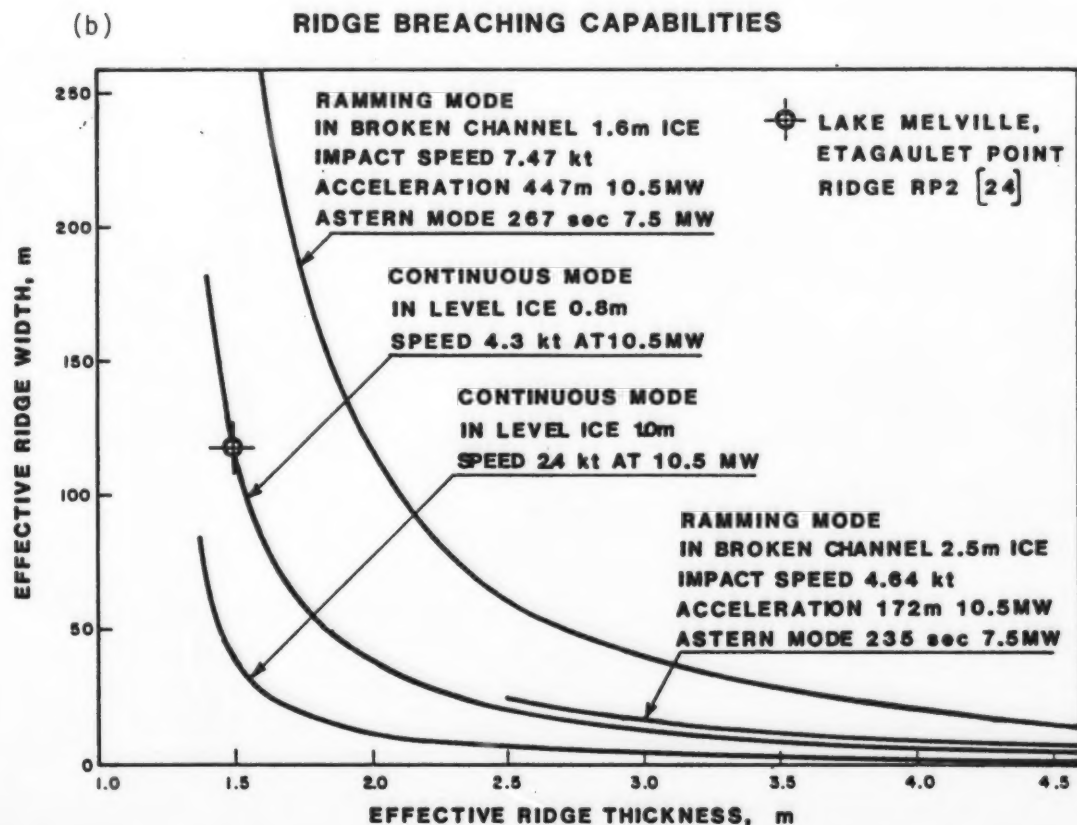
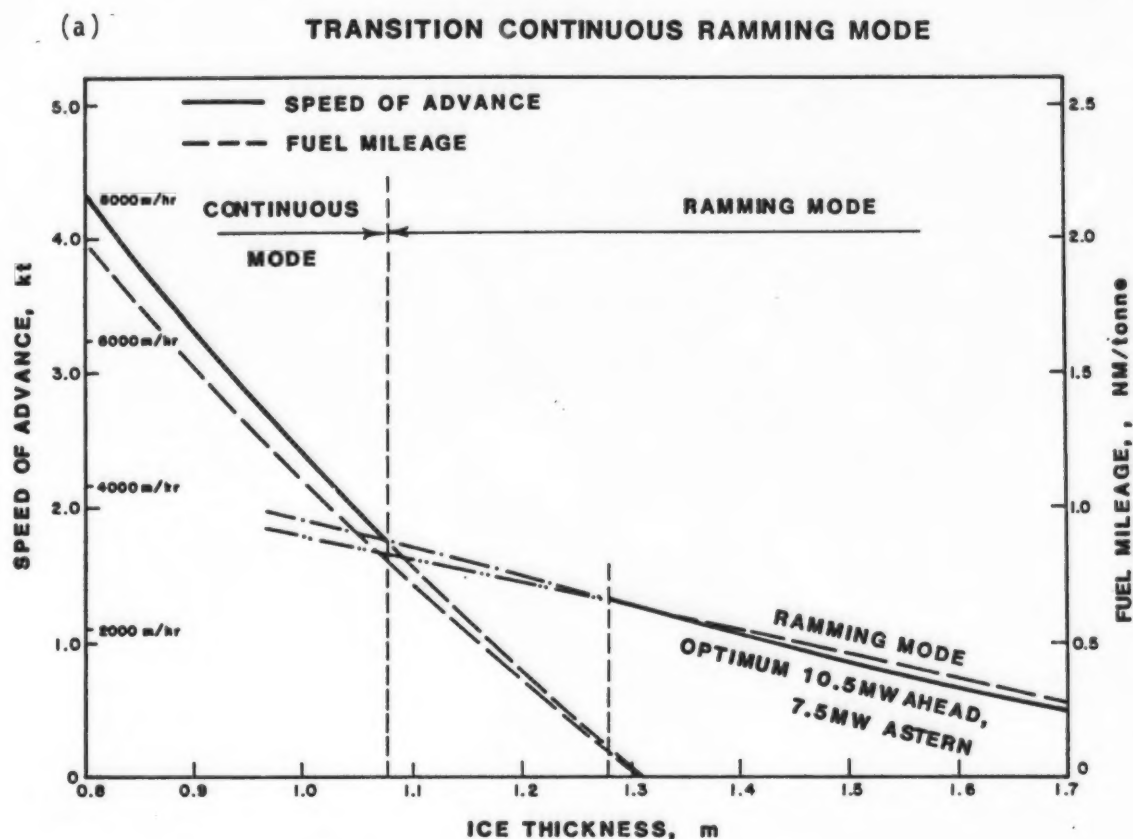


FIGURE 10



- on ice conditions,
- application of full power ahead,
- fast and efficient pitch reversal,
- maintaining full power during the penetration, with start of pitch reversal to astern pitch just before the ship comes to a halt.

The selection of the ship operation procedure can be made using Figure 11, which is drawn for only one power combination. The figure shows the various ship operation parameters, of which only the astern mode time depends on the astern power. The other parameters are fixed by the ahead power. The required astern mode time (time from start of backing of ship to start of fast pitch reversal to ahead pitch) and the acceleration distance (obtained at the end of the backing phase and required to achieve the optimum impact speed) can be read from the Figure for the ice thickness.

For example for ramming with full power ahead and a power level of 7.5 MW astern in ice thicknesses of 1.6 m and 2.5 m, the following results may be obtained using the proposed chart:

|                                                                                         |       |       |
|-----------------------------------------------------------------------------------------|-------|-------|
| - ice thickness (m)                                                                     | 1.6   | 2.5   |
| - required optimum impact (kt)                                                          | 6.35  | 4.0   |
| - required acceleration distance (m)                                                    | 192   | 75    |
| - duration of 7.5 MW power astern (sec)                                                 | 162   | 130   |
| - fast pitch reversal to full power ahead for stopping and direct start of acceleration |       |       |
| - speed of advance (Figure 9.b ) (m/hr)                                                 | 1120  | 230   |
| - fuel mileage (Figure 9.b ) (NM/tonne)                                                 | 0.358 | 0.077 |

The fuel mileage can be increased by reducing the astern power at the expense of speed of advance. In that case only the astern mode time will have to be adjusted.

It should be noted that efficient execution and good timing of the astern mode followed by the stopping maneuver, are crucial in reaching the desired acceleration distance without unnecessary time losses. Then full power should be applied during the entire acceleration phase to achieve the optimum impact speed within the acceleration distance. Also during the penetration phase, full power operation is effective as long as the ship makes penetration progress. Towards the end of the penetration phase the progress is slow. Therefore, this time can be better used for pitch reversal in preparation for the start of the next ramming cycle.

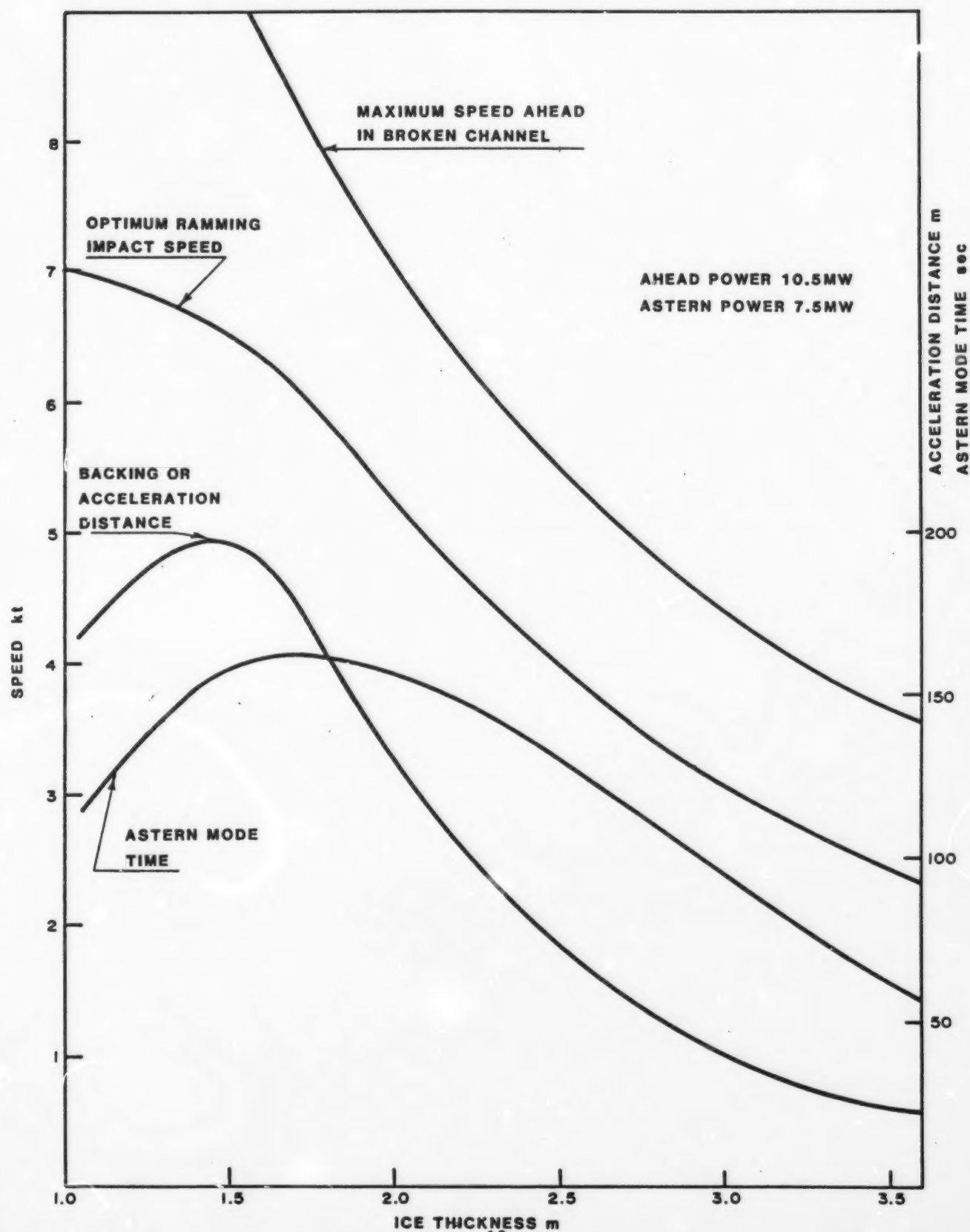
#### 4. EVALUATION OF OPERATIONAL ASPECTS

##### 4.1 Evaluation of CASPPR Power Requirements

According to Schedule G of CASPPR as amended in 1977, the minimum power requirement for the MV ARCTIC is 4.2 MW. The actual installed power is 11 MW or it is 162% over power. For a Class 2 ship, the MV ARCTIC would be required to proceed continuously in 0.61 m thick level ice without stopping. However, with its installed power, Schedule G

FIGURE 11

RAMMING STRATEGY



calculation would render the ship capable of proceeding through 1 m thick ice (a little over Class 3). Indeed, the MV ARCTIC was observed to go through 1.07 m thick ice continuously.

In the ramming mode, a similar improvement of performance was observed. Using the models developed in this study Figure 12 was produced to demonstrate this effect. It should be noted that the effect of over power is more obvious in less thick ice closer to the transition zone, and the advantage of over power declines in thicker ice. However, there is at least a 25% extension of the ship's capability due to over power.

#### 4.2 Evaluation of Design Features

MV ARCTIC has been designed with some unique design features for an ice class ship. These include bubbler system, propeller nozzle and others. From the point of view of ramming operation efficiency a limited evaluation was made of the significance of such features.

It has been shown that the bubbler system has some favourable effects in ramming. However, the improvements could not be completely separated and quantified due to the poor execution of some ramming series.

However, it was found that the bow trim was equally effective to the bubbler system. From an operational point of view it probably has more advantages since it does not require additional power to operate. Nonetheless, in some cases (when the ship is fully laden) it may not be feasible to maintain a favourable trim position when breaking ice.

#### 4.3 Instrumentation and Data Acquisition System

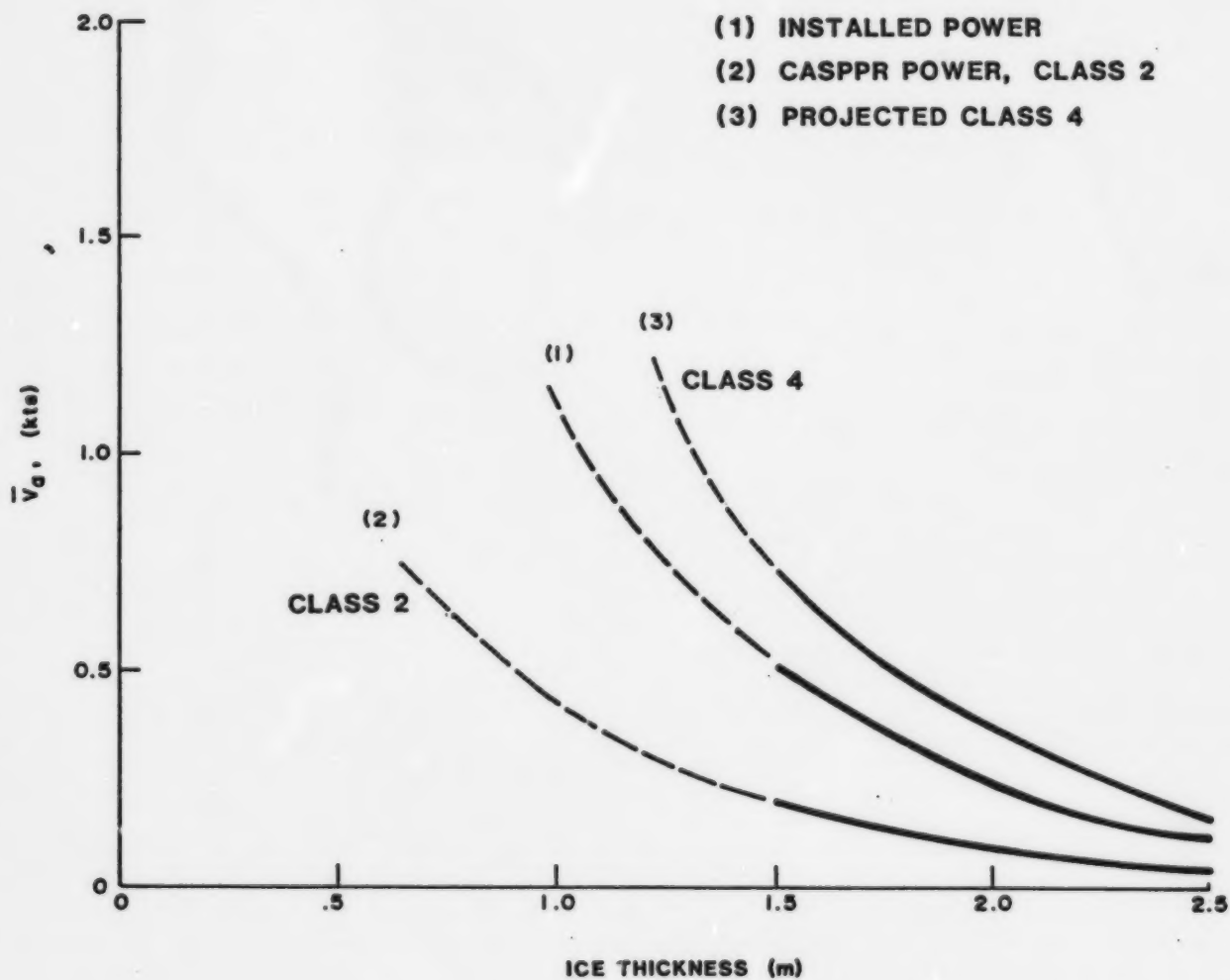
The instrumentation and data acquisition system was designed for use over a wide range of ship operations. With regards to the specific operating condition of backing and ramming, the system was deemed to have performed quite well with respect to a number of measured parameters. Unfortunately, the few areas where the system's performance was felt to be lacking, were coincidentally, the most important ones for the analysis of backing and ramming.

Data acquired on shaft torque, shaft thrust, shaft rpm and propeller pitch were found to be of high quality and reliability. Throughout the three shipping seasons shaft RPM was not operational the entire time, but when operating gave quite acceptable results.

Probably the single most important parameter for ramming cycle analysis is ship speed from which distance, acceleration and resistance are derived. Inaccuracies in the ship speed record therefore, have a crucial impact upon data analysis. Therefore, the method of speed measurement was inadequate for the purposes of monitoring transient speeds during ramming. Sampling rates for speed were inadequate and in the future a sampling rate of at least 10 Hz is recommended particularly for short rams in thick ice. Other channel sampling rates were acceptable. Fuel measurement was inadequate and resulted in interpreta-

FIGURE 12

COMPARISON OF THE EFFECTS OF INSTALLED VERSUS CASPPR LEVELS



tion problems. A better solution would be to incorporate a flow meter in the fuel line for direct measurement.

In addition to the above diagnosis, it is extremely useful to the analyzer as well as the designer to have proper documentation of the ice characteristics. Time must be allowed during the trials for complete documentation of the ice characteristics. While this cannot be attributed to lack of equipment or appreciation, the test plan and test director must pay proper attention to documentation of ice characteristics.

## 5. CONCLUSIONS AND RECOMMENDATIONS

Based on the methods developed during this study and the analysis of a limited number of ramming cases obtained during dedicated trials in the Admiralty Inlet, 1981, the following conclusions may be made:

- a) The overall quality of the data was generally good. The data base has proven to be very suitable for analysis, the results of which provide a better understanding of the ramming process as well as an indication of the potential for improvement of performance.
- b) Data reduction instrumentation and methodology were developed and applied successfully to most cases. However, two major shortcomings were encountered and were related to:
  - i) Poor accuracy and reliability of the doppler log records particularly during backing and at low speeds.
  - ii) Insufficient data on ice conditions and particularly on pressure ridge characteristics.
- c) The speed of impact significantly influences the average speed of advance. There exists an optimum impact speed for every ice thickness. When adopting optimum ramming strategy, a speed of advance of 0.65 knots or 1210 m/hr can be achieved in 1.6 m level ice with an impact speed of 6.35 knots. In level ice with a thickness of 2.5 m, an optimum impact speed of 4.0 knots can result in a speed of advance of 0.124 knots or 230 m/hr. The values are for full power ahead and 7.5 MW astern.
- d) The bubbler system appears to have an influence on the MV ARCTIC performance in the ramming mode. However, it does not appear to offer a distinctive economic advantage. The assessment was necessarily qualitative due to the size and distribution of the core database during dedicated trials.
- e) The ship trim was tested in two conditions; bow up and level trim. The former case was notably advantageous in very thick ice (or pressure ridges). Insufficient data was available for evaluation under different conditions. However, the bow

up position appears to have an equal effect as the bubbler but it is more economical to use.

- f) Thrust cut-off during ramming is a detrimental practice in ramming. Based on analysis and results of the present study, thrust cut-off adversely affects the speed of advance without offering a corresponding economic advantage (in terms of proportionally lesser fuel consumption).
- g) The fuel mileage (NM/tonne) is directly related to the ice thickness in an exponential form. It is also shown that the fuel mileage is directly proportional to the speed of advance.
- h) Performance components were optimized to determine the maximum capability of the MV ARCTIC. The following has been found:
  - i) In level ice ramming the maximum ice thickness is of the order of 3.6 m.
  - ii) In first-year pressure ridges in 1.6 m thick ice, the MV ARCTIC can breach ridges having an effective thickness of 2.8 to 4.1 m. In thick ice cover any first year ridge will slow the progress to unacceptable levels.
- i) Performance predictions based on trend analysis have indicated that the performance of the MV ARCTIC in the ramming mode of operation would be better in both speed of advance and fuel mileage with a higher installed power. A power increase of 10 percent would improve the speed of advance by 10 percent and the fuel mileage by about 5 percent. The use of reduced power in ramming operations would reduce the performance with approximately the same percentages.
- j) The transition point for continuous to ramming mode is estimated at an ice thickness of 1.08 m.
- k) Based on cycle time analysis it is concluded that the MV ARCTIC performance in ramming can be improved significantly by: optimization of impact speed, increasing the power level during backing in broken channel, minimization of thrust reversal intervals (a major source of hidden time losses) and elimination of time loss at the end of a ram. These measures DO NOT require any expensive refitting or improved hull geometry, they only require the proper application of the best ramming strategy.
- l) Performance simulation of the MV ARCTIC ramming performance has been successfully demonstrated. Proper performance simulation is instrumental in developing proper understanding of the key elements of a successful ramming strategy.
- m) Models for the MV ARCTIC broken channel ahead and astern have been developed.

- n) The installed power of the MV ARCTIC is greater than CASPPR minimum requirements. It first extends level ice continuous mode capability to 1.0 m and at this thickness it improves the ramming performance by 162 percent. The effect of over power decreases to 126 percent at a speed of advance of 0.05 knots.

## 5.2 Recommendations for Designers and Operators

Based on the results of this study, a few recommendations may be made to aid in design and operation of similar ships in the future.

From a design point of view it may be recommended that:

- a) The stern design should be modified to minimize ice resistance to ship motion astern. While this does not impose a penalty on icebreaking efficiency ahead, it can significantly influence the ship performance in ramming.
- b) A hull design which leaves lesser ice in the channel is more desirable if the ship is to operate in the ramming mode for a significant length of time. Basically a lower broken channel resistance should be sought and a compromise design may be necessary.
- c) Measures should be taken in the bow design to prevent wedging at the end of a ram. Particular attention should be paid to ice under lateral pressure. Low friction coatings may be used to minimize the possibilities of wedging under normal conditions of operation thus minimizing the time losses.
- d) The propeller design requires a balance between service speed in open water and ice going conditions which depends on the operational profile. In the case of the MV ARCTIC, the nozzle design is important. The nozzle is a good feature for highly loaded propellers and provides additional thrust which is extremely beneficial in the ramming mode. It usually means a small disadvantage at service speed in open water. The MV ARCTIC nozzle apparently optimized for ahead mode, is a compromise of low and high speed while the performance is sacrificed in the astern mode. This is reflected in the relatively low effective thrust developed while going astern, which degrades the ramming performance. A nozzle also reduces propeller ice milling although the nozzle propeller is more expensive than an open propeller, it has to be considered in the overall ship design especially when the ship is required to operate under ice conditions. When the ramming mode of operation forms an important aspect of the operational profile of the ship, it may be worthwhile to consider a propeller/nozzle design that is optimized for low speeds ahead and astern, to improve the ramming capabilities.

From an operations point of view we may recommend:

- a) Successful ramming strategy can be adopted through proper selection of optimum impact speed, based on ice conditions, determination of the required procedure of ship operation based on power and fuel constraints, and accurate and decisive execution of the procedure with fast pitch reversals, avoiding time losses between backing and acceleration phase or at the end of the ram prior to the start of the next ram.
- b) Utilization of full power ahead without hesitation or interruption is essential, since otherwise both speed of advance and fuel mileage will be lower.
- c) Utilization of astern power is a matter of trade-off between speed and fuel economy. A power of 7.5 MW seems a good compromise.
- d) Routing optimization can easily be accomplished onboard and in real time provided that the ship performance under various ice and environmental conditions are well understood and that ice and weather conditions can be made available to the ship as they become available. This is now possible via satellite communications and its usefulness is obvious.
- e) If the vibration level in the astern operation imposes a restriction on the power level which can be applied in the backing mode, it may be worthwhile to investigate the causes of such vibrations and eliminate them. The only limitation is vibration caused by external sources such as propeller ice milling which can only be dealt with through design modification.
- f) A test program in case of future trials should be set up with the results of this study in mind to confirm the MV ARCTIC performance predictions and to expand the present data base.